MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

GUIDE TO THE

GEOLOGICAL MODEL OF INGLEBOROUGH AND DISTRICT.

BY

AUBREY STRAHAN, M.A., Sc.D., F.R.S.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY

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230. AMMANFORD	1 6	1 6	2 6
231. MERTHYR TYDFIL ..	1 6	1 6	1 6
232. ABERGAVENNY ..	1 6	1 6	2 0
246. WEST GOWER	1 6	1 6	0 8
247. SWANSEA	1 6	1 6	2 6
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341. WEST FLEET.. ..	—	1 6	10 6
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343. SWANAGE	—	1 6	
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PREFACE.

The construction of a relief-model of the Ingleborough District by Mr. J. Foster Stackhouse has afforded an opportunity of adding to the series of geological models exhibited in this Museum. The model when purchased was plain, but its colouring has been carried out in this office by Mr. H. W. G. Williams under the superintendence of Dr. Strahan. Upon it are shown the geological formations, the faults, the caves and swallow-holes and underground water-courses, and a few contour-lines, with a small amount of topography. Glacial striæ are inserted, but glacial drift is omitted in order to give prominence to the solid geology, upon which the main orographical features depend.

This Guide has been written with a view to the requirements of students in physical geology. As in the case of the Guide to the Purbeck Model, it is accompanied by two Plates, one showing the uncoloured relief-model, while the other gives a geological map of the same region on the same scale. These Plates are designed with a view to making it possible for the reader to follow the description given in the guide apart from the model.

J. J. H. TEALL,
Director.

Geological Survey Office,
28, Jermyn Street, London.
5 September, 1910.

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(From a photograph of the Model.)

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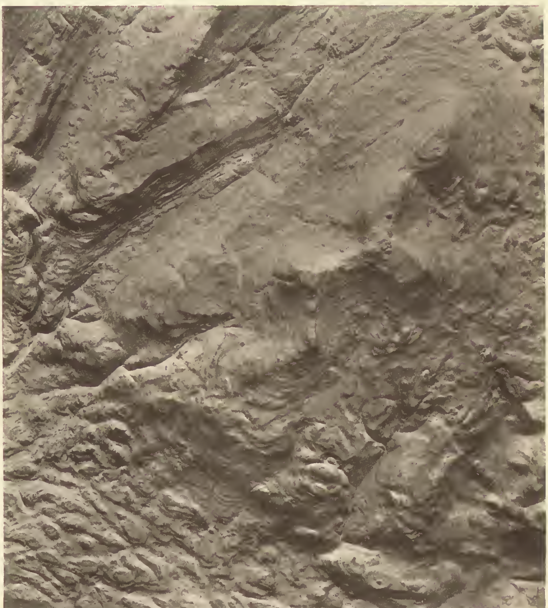
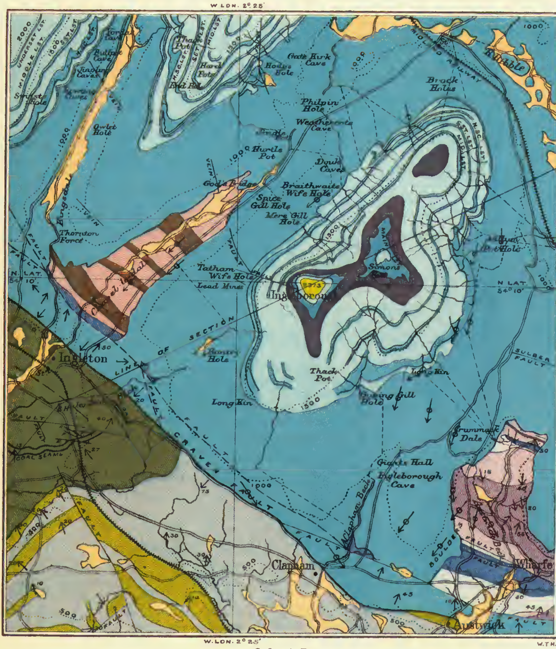


INGLEBOROUGH



SCALE

0 1 2 3 4 Miles.

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Slates with Grits	INGLETONIAN SERIES	UNKNOWN

15 *Indicates dip of strata, the angle in degrees.*

Glacial striæ.

1500 *Contour lines.*

The direction of underground streams, where known.

Ordnance Survey, Southampton, 1910.

GUIDE TO THE

GEOLOGICAL MODEL OF INGLEBOROUGH AND DISTRICT.

Introduction.

The original model of Ingleborough, of which replicas are produced by the Geographical Model Works, was prepared by Mr. J. Foster Stackhouse, F.R.G.S. According to the advertisement it was constructed by "building up a series of accurately gauged layers cut to the contours as shown in the 6-inch maps of the Ordnance Survey and verified, where necessary, by personal observation of the district. This laminated structure was then covered with a special composition which was moulded to the actual surface-representation at each part. The vertical scale is nearly double the horizontal scale in order to throw the indentation of the ground into the strongest possible relief. Even the river beds are represented by actual indentations. A perfect representation of the actual formation of the ground is thus obtained." The horizontal scale therefore is about 6 inch = 1 mile, or $\frac{1}{10560}$ of nature; but the vertical scale proves to be rather larger than stated above, and to be $2\frac{2}{3}$ as great as the horizontal scale—that is, $\frac{1}{3960}$ of nature. An elevation of one inch on the model approximately represents 300 feet.

Configuration.

Plate I. is reproduced from a photograph of the model in the form in which it is issued for sale. In this condition it shews the form of the surface with fidelity, but is devoid of all landmarks, such as rivers or villages.

Certain broad features at once attract attention. The country represented in the south-western corner of the model is clearly a gently undulating plain, while the rest may be described as part of a plateau deeply dissected by a series of broad and open valleys which lead down to the plain. These two types of country are separated by a sharply defined step which runs in an almost straight line from south-east to north-west, and the rivers as they descend this step cut deep gorges in it, but pass out into open valleys on entering the plain. The north-eastern corner of the model includes a small portion of a distinct drainage-system. The dissected plateau forms part of the West Riding dale-district.

Geological Structure.

The geological surveying of the Ingleborough district was commenced in 1870 by Professor T. McK. Hughes, R. H. Tiddeman and W. Gunn, but was revised and completed in 1883 by R. H. Tiddeman, W. Gunn and C. Fox Strangways. The geology, with some modifications to be noted later, has been transferred to the model from the 6-inch maps prepared in 1883, and is

reproduced in Plate II., so far as the small scale admits. It must be mentioned, however, that all superficial deposits of glacial age are omitted both on the model and in Plate II. in order to give prominence to the solid geology, the primary object being to illustrate the dependence of land-form upon geological structure. The discontinuity of some of the outcrops upon the model is due to the solid rocks being effectually concealed by glacial drift.

The explanation, not only of the differences in the types of country mentioned above and of the sharp line of separation between them, but even of the subsidiary features on the hill-sides, now becomes apparent. We see that the low plain is underlain by Coal Measures, with Millstone Grit rising from beneath them, and recognise it as part of the small Ingleton coal-field.

The dissected plateau, on the other hand, consists of the alternations of shales, sandstones and limestones, which constitute the Yoredale Beds, based upon about 600 feet of solid limestone known as the Great Scar Limestone. The dissection has reached such a stage that the once-continuous Yoredale Beds have been cut up into outliers, while the surface of the Great Scar Limestone has been laid bare in the form of a terrace, upon which the outliers stand as though on a pedestal. It has even gone to such a depth as to expose to view parts of the ancient platform upon which the Great Scar Limestone itself reposes. All the formations thus exhibited impress upon the landscape their individual characters. Observe, for example, the little platform on the top of Ingleborough, once seen never to be forgotten, which is formed by a small relic of Millstone Grit; or the great shoulder which is added to the hill by some Yoredale sandstones. Or again, compare the steep, crumbling slopes formed by the Yoredale shales, cut by the weather into cwms, with the broad surfaces of the more resistant Great Scar Limestone.

Succession of Strata.

We have now to ascertain how these two blocks of country came to be placed in juxtaposition. We may begin by constructing a complete column of the strata in their order of superposition, in order to determine what originally was the relative position of the formations which underlie the plain to those which form the dale-district. Including the strata proved in boreholes, we find the following descending sequence of formations :—

			Feet.
Carboniferous.	Coal Measures.	Red marls with occasional shales and ironstones, proved in a borehole ; top not seen	620
		Grey and dark shales with occasional sandstones and thin seams of coal and cannel, proved in a borehole to a thickness of ...	605
		Gap of unknown amount.	
		Measures with the Main and other seams of coal	300
		Measures estimated at	550
	Millstone Grit.	Shale and sandstone, found in boreholes to a thickness of	600
		Gap of unknown amount.	
		Ingleborough Grit	80
	Limestone Series.	Yoredale beds, about	950
		Great Scar Limestone, with impersistent conglomerate at base	600

Great unconformity.

Silurian	Coniston Flags.	Shales, &c. (Horton Flags).
		Grits, &c. (Austwick Grit).
		Shales, &c. (Austwick Flags).
	Stockdale Shales.	Shales with calcareous mudstone (not distinguished on the model).
Ordovician	Coniston Limestone Series.	Ashgill Shales, and shales with ashes.
		Calcareous shales and limestone (Coniston Limestone).
"Ingletonian"		Slates and grits with conglomerate.
Igneous Rocks		Dykes of mica-trap in the Ordovician rocks.

The Carboniferous Sequence.

Firstly with respect to the plain. The northern part of it is occupied by Coal Measures containing the Main and other seams of coal. The inclination of the strata varies somewhat in direction and amount, but that it is generally northwards may be inferred from the fact that the Millstone Grit rises to the surface to the south. This is confirmed by the coal-workings which have been carried down northwards from the outcrops of the seams to a depth of upwards of 100 yards, and with an average slope of 1 in 4. Below the workings there is a group of strata which contains no known coal-seams, but which is classed as Coal Measures. The base of this group reaches the surface about 2,250 feet south of the outcrop of the lowest coal-seam. In that distance it would ascend 562 feet with a dip of 1 in 4, and as the true thickness of the group, measured at right angles to the stratification instead of vertically, would be somewhat less, we may allow in round numbers 550 feet for the thickness of measures below the coal-seams.

To continue the section we may use the information gained in two boreholes which have been put down at or close to the base of the Coal Measures outside the area covered by the model. The borings traversed alternations of shale and sandstone to a depth of 600 feet. These are the strata which crop out to the south of the coal-field, and are shewn on the model as Millstone Grit. Their base was not reached in the borings.

We have now determined 1,450 feet of strata—namely, 300 feet of Coal Measures which lie above the seams and have been traversed in shafts, 550 feet of Coal Measures below the seams, and 600 feet of Millstone Grit.

Above all these, but how far above is doubtful, we must place the strata which were proved in the borehole marked on the map forming Plate II., and on the section given on p. 6. This borehole was designed with a view to proving the depth to the coal-seams, but though it was carried to a depth of 1,354 feet, that object was not accomplished. It traversed about 129 feet of glacial drift, 620 feet of red marls with occasional shales and ironstones, and then grey and dark shales with occasional sandstones. A coal, 6 inches thick, was found at 809 feet, and a cannel, 18 inches thick, at 839 feet, but the workable seams were not found. It is conceivable that the seams were passed through and not recognised, but more probably they were not reached. At any rate, the red marls are some of the highest Coal Measures existing in the coal-field. Let us suppose that the boring stopped just short of the coal-seams. We then have 1,225 feet of strata (*i.e.*, the total depth of the boring minus the thickness of the glacial drift) to add on to the column previously determined, making a total of 2,675 feet. The base of the Millstone Grit therefore must lie at a depth of not less than 2,804 feet below

the top of the glacial drift (that is, the surface of the ground) at the site of the boring.

Let us now pass to the eastern side of the region illustrated by the model and construct a column of the strata there exposed to view in the sides of the hills. The geology in its broad outlines can be read at a glance. Below the minute outlier of Millstone Grit which forms the table-top of Ingleborough, we find displayed shales with a thin band known as the Main Limestone ; this in turn reposes upon a broad platform of which Simon Fell forms part, and which owes its existence to some thick sandstones. From the edge of the platform we descend rapidly over a succession of shales with thin limestones, till we reach a second platform, the pedestal upon which all these strata are based. This is formed by the Great Scar Limestone.

This sequence of strata is familiar to all dwellers in the dales. The sandstone of Ingleborough top is the basal grit of the Millstone Grit. The alternations of sandstone, shale and limestone below it constitute the Yoredale Beds, so named by Professor Phillips after the dale of that name. With the Great Scar Limestone they form collectively the Carboniferous Limestone Series. The Yoredale limestone-beds, thin as they are, have been traced for hundreds of miles around the hills and along the valleys of the dale-district under the names shewn upon the model. Lastly in one or two spots there may be seen, below the Great Scar Limestone, patches of conglomerate and calcareous breccia, known as the Carboniferous Basement Beds. This rests on more ancient rocks of a wholly different aspect, which reveal themselves here and there where the valleys have been cut through all the Carboniferous rocks. Here, however, the break in the succession of strata is so complete that we may defer consideration of the older formations till we have completed our investigation of the Carboniferous sequence. We have still to ascertain the relative position borne by the Coal Measures and Millstone Grit of the western to the Carboniferous Limestone Series of the eastern part of the region.

The measurements of the limestone-series, as displayed in the sides of Ingleborough, have been determined as follows* :—

Ingleborough.

			Feet.
Millstone Grit.	Coarse rubbly grit of Ingleborough summit		60
Carboniferous Limestone Series.	Yoredale Beds.	Shales	120
		MAIN LIMESTONE	50–60
		Sandstone, with some shale† ...	200
		Shale, with some sandstone ...	130
		Limestone (with shale) ...	8–10
		Shale and sandstone	60
		MIDDLE LIMESTONE	15–20
		Sandstone and shale	150
		SIMONSTONE LIMESTONE ...	25–30
		Sandstone and shale	100
		HARDRAW SCAR LIMESTONE...	30–40
		Shales and limestone	30
	GREAT SCAR LIMESTONE, about		600
	Basement Beds, impersistent.		

* 'The Geology of the Country around Ingleborough' (*Geol. Survey Memoir*), 1890, p. 21.

† The Underset Limestone, which might be expected about 100 feet below the Main Limestone, is not recognisable in Ingleborough.

This succession of strata has been drawn to a scale of 200 feet = 1 inch and forms part of the Index to Colours which lies alongside the model.

We may now compare the relative positions of the two columns of strata we have determined. At the borehole we have ascertained that the Ingleborough Grit is not less than 2,804 feet below the surface of the ground. Assume it to be 2,810 feet. The surface is 425 feet above Ordnance Datum. The Ingleborough Grit, therefore, by our assumption, would be reached at not less than 2,385 feet below Ordnance Datum. The trigonometrical station on the top of Ingleborough is 2,373 feet above Ordnance Datum. This stratum, therefore, is at least 4,758 feet higher in the one place than it is in the other.

Such a difference in level would not be remarkable if the strata were highly inclined, but, so far at any rate as regards the Yoredale beds, the dip is uniformly gentle. It will, however, be useful to go further into this matter and ascertain exactly what is the direction and amount of the dip of these beds. We will proceed therefore to draw a section passing through Ingleborough top in the direction of the borehole (Figure, p. 6).

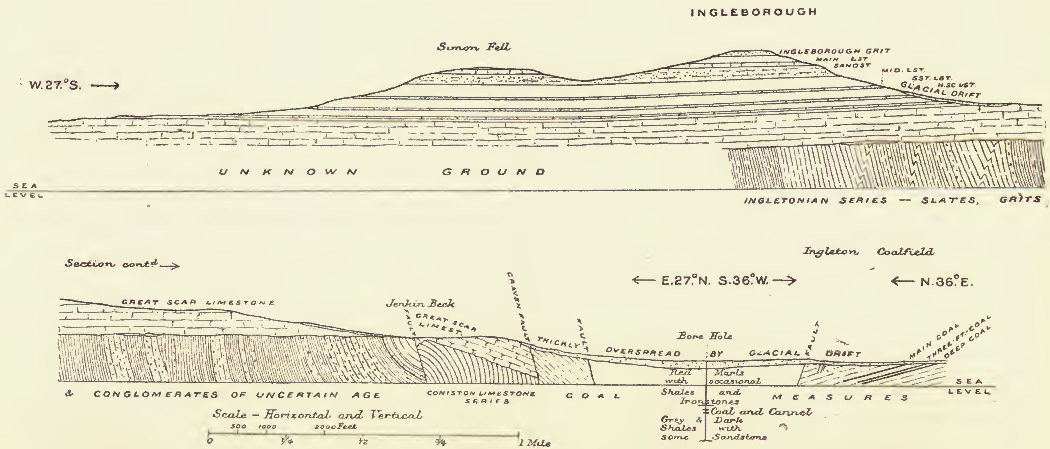
Construction of a Section.

The section, a copy of which lies alongside the model, is constructed as follows. The six-inch maps shew contour-lines at intervals of 25 feet up to a height of 1,200 feet and thence upwards at intervals of 50 feet. Having ruled the selected line of section upon the map and a line of corresponding length upon a sheet of paper, we prick off upon the latter the positions of the various contour-lines. From each position we raise a perpendicular corresponding in height to the height of the contour-line, and join up the terminations of the perpendiculars. We thus obtain the profile of the ground on a true scale (that is on the same scale for vertical and horizontal measurements), and with sufficient accuracy for our purpose.

We may now transfer to this profile the outcrops of the various strata, and, knowing that the dip is fairly uniform, we might tentatively rule lines joining up corresponding outcrops, in order to represent the underground positions of the strata. Thus we should rule a line from the top of the Great Scar Limestone on the south-western side of Ingleborough to the top of the same bed on the north-eastern side, and so also for each of the limestones and sandstones which are shewn upon the map.

This, however, we should do tentatively, for as a fact a further check is possible, upon applying which we shall find that lines so ruled would be seriously wrong. In fact the error would shew itself at once, for the base of the Yoredale sandstone, thus ruled, rises above the profile between Ingleborough and Simon Fell in the line of section, whereas it is actually about 60 feet below it, as shown on the model and in Plate II. The dip therefore is not uniform, and we must ascertain where the irregularity lies.

Section along the line shewn on the map



Determination of Dip.

Firstly, to ascertain the exact direction of the dip, which of course may or may not agree with that of our line of section. Suitable data are obtainable on the outcrop of the Hardraw Scar Limestone. That bed crops on the 1,400-feet contour at two points, one to the north-west, the other to the south-east of Ingleborough. A line joining these two points gives the direction of 'dead level' in that bed, or in other words the strike. By reference to the line of latitude marked on the edge of the map, we ascertain the strike to be W. 27° N. The dip therefore is N. 27° E.

From this line of 'dead level' draw a perpendicular through the southernmost known exposure of Hardraw Scar Limestone. The length of this line is approximately 8,800 feet, and the bed in that distance rises 150 feet. The amount of the dip therefore is 1 in 59 (nearly).

From the same line of 'dead level' draw a perpendicular to the northernmost exposure of Hardraw Scar Limestone. The length of this line is 12,000 feet, and the bed falls in this distance 150 feet. The amount of the dip therefore is 1 in 80.

It appears, therefore, that the dip is steeper under the southern part than under the northern part of the Ingleborough mass. In other words, the beds have a gentle synclinal structure. The exact form of the synclinal curve could, of course, be ascertained by drawing a series of lines of 'dead level' in any one bed and determining the gradient at frequent intervals. It may be noted that the syncline is the most effective form into which strata can be thrown as regards resistance to denudation. The survival of the outlier of Yoredale Beds which form Ingleborough is not unlikely to have been due partly to the existence of this gentle fold.

The Craven Fault.

But further examination of the model will shew that the beds do not continue to rise westwards. The Great Scar Limestone, for example, dips south-westwards all along its south-western margin at angles varying from 15°–20°, and again in the adjoining strip the Coal Measures dip in the same direction. There is therefore a sharp westward roll-down (uniclinal fold) along the strip which separates the Limestone and the Coal Measure regions. The roll-down, however, will not account for the observed facts. Thus it does not explain why the Great Scar Limestone, where it rolls over, is not followed on its western or upper side by the Yoredale Beds, and these again by the Millstone Grit and the Coal Measures in their proper sequence. So far from this being the case, some of the highest Coal Measures in the coal-field near Ingleton lie face to face with the Great Scar Limestone.

Two explanations suggest themselves. One involves the assumption that the Yoredale Beds never extended westwards over the plain, and that the Millstone Grit never extended over the area where Ingleton stands. This theory may be dismissed at once as being opposed to all the probabilities. Neither in the Yoredale Beds nor Millstone Grit is there any indication of the immediate neighbourhood of a coast-line; on the contrary, there is abundant evidence

in neighbouring parts of Lancashire and Westmoreland that the Carboniferous Limestone and Millstone Grit once overspread the whole area, and extended far westwards, and again that the coal-field is a small relic only of a sheet which extended far eastwards. The fact already noticed that the beds assume an abnormal dip along the line of separation between the two parts of the model further suggests that we must look for a different explanation.

The alternative theory is that the strata have been not only bent downwards towards the west but also broken across and displaced along the fracture—in other words, that the difference of level is due to a fault with a down-throw west. The evidence for this view is strong. In the first place the sudden flexure of the beds is proof of disturbance subsequent to deposition, and would itself lead us to expect fracturing. Secondly, there are at least three lines along which the relative positions of the formations can be explained on no other theory. One is marked by the interruption of the normal strike of the coal-seams before alluded to; along another Coal Measures, and widely different parts of the Coal Measures, lie face to face with the Carboniferous Limestone; while along a third line the Carboniferous Limestone is thrown against some of the older Palæozoic Rocks. These three lines are approximately parallel, and have a straightness and definiteness which is found only in faulted boundaries. The theory, therefore, that the strata are fractured and thrown down westwards, as well as bent downwards, is the only theory which is in accordance with all the evidence.

As a matter of fact, we are confronted here with a great dislocation the course of which is well known for a distance of 80 miles. It runs westwards past Settle, and then northwards past Kirkby Lonsdale up the Lune Valley, under the name of the Craven Fault. From Kirkby Lonsdale a branch of it ranges north-north-eastwards to Kirkby Stephen under the name of the Dent Fault, and from Kirkby Stephen it runs north-north-westwards along the Vale of Eden, under the name of the Pennine Fault. These three great fractures form the western limit of the elevated but deeply dissected plateau of gently inclined Lower Carboniferous rocks which constitutes the dale-district, and introduce the highly complicated structures which characterise the north-west of England. Everywhere they bring rocks of widely different age and character face to face with the dale-district rocks, and always they make themselves conspicuous by the change they produce in the character of the country.

The Craven Fault, as marked on the model, is the most important of a series of fractures. One of the series of associated faults traverses the coal-field near the borehole, while another branches out southwards from the Craven Fault. A third, sometimes known as the North Craven Fault, truncates the various inliers of Ordovician rocks but is of trifling throw as compared with the main fault. Regarding all these fractures and the folds of the intermediate strata as part of the same general movement, we may assign a width of about one mile to the Craven Disturbance.

The vertical displacement of the strata accomplished by combined fracture and fold varies greatly, but may be calculated by the following method to be not less than 5,375 feet near Ingleton. The

base of the Ingleborough Grit would, if the strata were prolonged at the observed dip, reach an altitude of 2,910 feet above the sea at the site of the borehole. We have previously ascertained that at that spot the top of that grit cannot be less than 2,385 feet below sea-level. The Ingleborough Grit is about 80 feet thick, so that its base would be 2,465 feet below sea-level, that is 5,375 feet below the position it would occupy if the folds and fractures which constitute the disturbance did not exist.

The date of this great master-fault can be determined approximately. That it was formed after the newest Coal Measures of the Ingleton-coal field has been shewn already, and it may be assumed that it came into existence simultaneously with other great dislocations which affected this part of the globe in the interval between the Carboniferous and the Permian periods. In the Vale of Eden however faulting on a comparatively small scale appears also in the Permian and New Red Sandstone along the line of the Pennine Fault, indicating that movement was renewed along the old fracture at some later date.

Pre-Carboniferous Rocks.

We paused in our account of the rocks underlying Ingleborough at the base of the Carboniferous system, but at four places a much older series of strata is exposed to view, namely in Chapel le-dale, in Jenkin Beck, in Clapham Beck and in Crummack Dale. The exposures are due to the rivers having excavated their valleys so deeply as to reach and to cut into the platform of older rocks on which the Carboniferous rocks repose, and they enable us to distinguish many interesting features in that ancient plain of denudation. In places the platform shews a remarkable evenness ; along Chapel-le-dale for example its featureless surface coincides with the dip of the Carboniferous beds so closely that it must evidently have formed an almost dead-level plain when those beds were laid down upon it, and this despite the fact that it is composed of rocks greatly differing in hardness. In Crummack Dale on the other hand the surface undulates so considerably that in part of the western side it rises 350 feet in less than a mile, while in the next mile it falls again 200 feet. Mr. Dakyns remarks that the line dividing the two formations runs sharply up and down 20 or 30 feet in places, while the bedding of the limestone keeps nearly horizontal. In other places the limestone and Basement Beds have been deposited against a boss of the old rocks, and in one case though the limestone is horizontal, its base-line runs down as much as 150 feet in about 300 yards.* But the subdued form of the platform and the comparative scarceness of such features do not suggest the unaided action of subaerial denudation ; the final shaping, at least, must have been the work of the Carboniferous sea.

The rocks out of which the platform has been carved exhibit structures which obviously have nothing in common with those of the Carboniferous rocks. They are tilted up at high angles, folded and cleaved, while the Carboniferous Limestone reposes tranquilly upon their truncated edges, giving one of the finest exhibitions of

* 'The Geology of the Country around Ingleborough' (*Geol. Survey Memoir*), 1890, p. 23.

an unconformity to be seen in the British Isles. Clearly the earth-movements by which the tilting and cleavage were produced began and ended before the Carboniferous period commenced. We find, therefore, within the area illustrated by the model, the records of earth-movements of two wholly different geological periods. The one, of pre-Carboniferous age, was a period of intense compression in the direction SW–NE, resulting in folding and cleavage, with upheaval and its necessary concomitant, denudation; the other, of post-Carboniferous age, resulted in the series of great fractures known as the Craven, Dent and Pennine Faults, as well as other disturbances outside the region with which we are concerned.

For our knowledge of the succession of the older strata we are indebted chiefly to Professor Hughes,* W. Gunn,† Dr. Marr‡ and Mr. Rastall.§ The oldest rocks are those exposed in Chapel-le-dale. These were at first doubtfully classed as 'Lower Silurian' (or as they would now be called Ordovician), chiefly on account of their association with a limestone which could be recognised as being of Ordovician age by its fossils. They themselves, however, have yielded no fossils, and their association with the limestone is as likely to be an accident of faulting, as the result of natural superposition. That they are of much earlier date is probable, but in view of the uncertainty it is convenient to use a local and non-committal name, such as Ingletonian Series, as suggested by Mr. Rastall.

The series consists of slates and grits, usually of a greenish tint, with a conglomerate composed mostly of white or grey quartz-fragments with red felspar. The dip, always high, is generally to the south-west, so as to suggest that there is continuous ascending sequence from God's Bridge down Chapel-le-dale. This led Mr. Gunn to believe that there must be here exposed about 10,000 feet of strata, but Professor Hughes points out the impossibility of detecting how much of this apparent thickness is due to repetition by folding, for in strata which have undergone such intense compression folds are often packed so closely as to simulate a continuous sequence.

As the result of an examination of the conglomerate Mr. Rastall concludes that the material has been derived from igneous and metamorphic rocks such as occur in an Archæan complex, and that the beds may belong to the Torridonian, or, as suggested in 1874 by W. T. Aveline, to the Longmyndian group.

The Coniston Limestone series of the Ordovician group lies next to the higher members of the Ingletonian series. The junction is seldom visible, and when visible is difficult to interpret. Professor Hughes observed in the gorge below Thornton Force some thin papery shales presenting a somewhat intermediate character between the two formations, but inclined to the belief that the shaly appearance was due to rearrangement by movement long subsequent to deposition. Dr. Marr previously had searched, but in vain, for proof of a passage between the Ingletonian and Ordovician strata.

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* *Geol.. Mag.* for 1867, p. 356 and *Proc. Yorksh. Geol. Soc.*, Vols. XIV–XVI., 1900–08.

† 'The Geology of Ingleborough' (*Geol. Survey Memoir*), 1890.

‡ *Geol. Mag.* for 1887, p. 36 and 1892, p. 104.

§ *Proc. Yorksh. Geol. Soc.*, Vol. XVI., 1906–08.

The following descending sequence is recognised by Dr. Marr in the Ordovician group* :—

Blue flaggy shales with fossils characteristic of the Ashgill Shales.
Blue silvery shales.
Ashes.
Calcareous blue shales.

The Ashgill Shales are not well developed, but some characteristic fossils have been yielded by some black shales 200 yards south-west of Wharfe. The Coniston Limestone is represented in the lower part of the sequence, but in a more shaly form than in its typical development in the north-west of England.

The Silurian group includes, in addition to the Coniston Flags, a representative of the Stockdale Shales, the sequence being :—

Coniston Flags.
Stockdale Shales with a basal conglomerate.

The Stockdale Shales consist of leaden-grey shales with a thin band of calcareous mudstone almost wholly made up of fragments of trilobites (zone of *Phacops elegans*). The conglomerate at their base was first described by Professor Hughes in 1867.†

The Lower Coniston Flags, which immediately succeed the calcareous mudstone, consist of laminated blue, slightly gritty flags, followed by about 1,000 feet of tough grits. These are known locally as the Austwick Flags and Grits. Above them come the Coniston Flags proper, or Horton Flags, which are about 2,000 feet thick. The well-known Moughton Whetstone occurs in the Lower Coniston Flags at the head of Crummack Dale.

Glacial Phenomena.

Glacial drift overspreads large areas round Ingleborough, but it has not been indicated on the model in order that prominence might be given to the outcrops of the rock-formations. The drift consists of subangular detritus of the local rocks, at times rudely stratified but more frequently heaped together without such arrangement. It is often piled up in the hummocks, ridges and crescentic mounds which are the characteristic signs of the agency of ice. It occurs as high up as 2,000 feet and probably more on the south-east side of Ingleborough, and on the flanks of the northern abutment it reaches to about 1,600 feet, but in the valleys and especially at the junctions of valleys it attains its greatest development and shows most conspicuously the moundy arrangement. The longer axes of the mounds coincide with the direction in which the ice moved, and the formation of these remarkable accumulations is attributable to rivers plunging down through the ice by crevasses, or flowing in tunnels under the ice.

Great boulders, some of many tons weight, were carried on the surface of the ice and dropped in abundance on the hillsides, sometimes at a higher level than the spot from which they were derived. The finest example of clusters and streams of boulders is to be

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* *Geol. Mag.* for 1887, p. 36.
† *Geol. Mag.* for 1867, p. 346.

found on Norber, one mile north of Austwick. They attracted the attention of Phillips in 1827, and have been frequently referred to since,* but the most complete description is that given by J. W. Davis, from whose paper the following quotation is made.

"The whole of the surface of the limestone plateau . . . is thickly strewn with masses of Silurian grit, some of these are of immense size and weigh many tons. Blocks 16 to 20 feet in diameter are not uncommon, some are so perched in the underlying limestone as to form rocking stones . . . In numerous instances the grits have served as a protection to the limestone beneath them, and they are now supported on limestone pedestals 18 to 24 inches in height. This circumstance leads naturally to the inference that, since the period during which the Silurian rocks were carried and deposited where they are now found, the surface of the limestone has been lowered, except where protected by the overlying masses of Silurian rocks, to the extent of nearly two feet." Further on he observes that some "are so balanced that they will rock and sway with a slight push, or are perched on the edge of the escarpment so that they appear almost incapable of resisting the action of a strong wind."

The boulders according to Mr. Davis lie in three streams, the principal of which approximately follows the 1,000-foot contour-line, while another stream takes a nearly parallel course but runs up to an elevation of 1,200 feet.

South of Simon Fell there lies a mass of limestone about 70 yards long and 40 yards in greatest breadth, which appears to have been brought from the Main Limestone on the top of the hill, a distance of not less than 700 yards.

In Chapel-le-dale there is a boulder of limestone three-quarters of a mile north-east of Ingleton, which measures 12 × 9 × 5 feet, and there are many others near by which can be traced to their sources higher up the dale.

Glacial striations are not uncommonly preserved on rock-surfaces which have been protected from weather by drift or by a big boulder. In Chapel-le-dale they run generally south-west, and though they are more frequently preserved on the Ingletonian rocks, they occur also on the limestone up to a height of 1,150 feet. Those to the south and south-east of Simon Fell are mostly indebted to boulders for their preservation.

Though varying slightly in direction according to the local configuration of the ground, the striæ maintain a general parallelism to the contours of Ingleborough. They sweep round the hill, not down it, and obviously are not the tracks of glaciers formed on Ingleborough and descending its sides. To go into the history of the glaciation of the region would lead us far afield, and it must suffice here to say that we are dealing with the local development of an ice-sheet, or one of a system of ice-sheets, which overran all the northern part of the British Isles. The ice in this particular area

* Phillips, *Trans. Geol. Soc.*, vol. iii. (1827), p. 13. R. H. Tiddeman, *Quart. Journ. Geol. Soc.*, vol. xxxviii (1872), p. 477. T. McK. Hughes, *Quart. Journ. Geol. Soc.*, vol. xlii. (1886), p. 527. Davis and Lees "West Yorkshire," pp. 200, 201, 267. J. W. Davis, *Proc. York. Geol. and Pol. Soc.*, N.S., vol. vii. (1880), p. 266.

moved generally south-westwards towards the plain, sweeping round Ingleborough and possibly, when at its maximum, nearly submerging it.* On reaching the plain it appears to have continued its course in a direction rather to the east of south.

Caves.

There are few places in the kingdom where the caves and underground water-channels, characteristic of limestone-formations, can be studied to greater advantage than round Ingleborough. The liability of limestone to underground erosion of this description is due to two properties, namely that it breaks more readily than it bends and is therefore apt to fissure ; and secondly that it is soluble in acidulated water, such for example as has picked up vegetable acids in its passage through the soil. As a result the limestone, though itself an impermeable rock, is traversed by widened fissures or bedding-planes, by more or less vertical shafts or chasms known as pots, swallow-holes or brock-holes, and by tortuous channels and irregular chambers. Underground channels of this description carry the whole of the water on the outcrop of the Great Scar Limestone, and frequently cause the temporary disappearance of streams across the narrow outcrops of the Yoredale limestones.

The water reappears at the surface on reaching an impervious stratum, either in the limestone or below it. Ingleborough Cave for example, which gives exit for much of the drainage of the south side of Ingleborough, opens out some distance above the base of the limestone ; Austwick Beck, on the other hand, issues from between the limestone and the impermeable lower Palæozoic rocks. Such issues are known locally as kelds.

All the caves which are accessible have been explored. Several are described in the Geological Survey Memoir on 'The Country around Ingleborough,' but for a more detailed account, and for a description of the methods of exploration, reference should be made to the Journal of the Yorkshire Ramblers Club. The underground courses followed by the water have been investigated by a joint Committee of the British Association and the Yorkshire Geological and Polytechnic Society.† By putting fluorescein and other substances in the water at its entry into a swallow-hole it became possible in many cases to identify the water at its issue. Wherever an issue has been connected with a swallow-hole the fact is indicated on the model and on the map forming Plate II. by a dotted line.

Gaping Gill (or Ghyll) is a nearly circular swallow-hole, 365 feet deep. About halfway down it communicates with a second shaft by a small lateral passage. The shaft ends in a chamber 480 feet long and 110 feet high. The water which descends Gaping Gill disappears in the floor of this chamber but at some former period has escaped by long passages at some height above the floor. These open out eastwards and have been explored for more than 600 yards. They contain fine stalactites. The water has been traced to a small pot a quarter of a mile to the east and thence to Ingleborough Cave.

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* Baugh Fell, 11 miles to the north, is glaciated over its summit, nearly 2,200 feet above the sea. 'The Geology of the Country around Mallerstang' (*Geol. Survey Memoir*), 1891, p. 193.

† *Journ. Yorksh. Geol. and Polytech. Soc.*, vol. xv., 1903–05, p. 248.

Ingleborough Cave, until the year 1837, had been explored for 80 yards only, but a curtain of stalactite having been broken through and some dammed-up water liberated, exploration was continued for a further distance of 700 yards, Fine stalactites and stalagmites were found behind the barrier and have received the usual fanciful names—one which extends from floor to roof gives the name to the Pillar Hall.

The stream which issues from Ingleborough Cave becomes known as Clapham Beck. About a mile below the cave it receives a tributary which issues at the junction of the Carboniferous Limestone and Silurian rocks. This water has been traced from a swallow-hole nearly 1½ miles to the west-north-west. The model shows well how totally independent are the open-air and the underground courses of this stream.

Long Kin is situated less than three-quarters of a mile from Gaping Gill and within the catchment-area of Clapham Beck, but the water which enters it emerges at Austwick Beck Head, as does also that from pots situated 400 and 1,000 yards north-east of Long Kin. Here again the underground rivers ignore the surface-features—they are guided by the direction of jointing and other planes of weakness, and in these cases possibly also by inequalities in the floor of old rocks on which the limestone rests.

Allum (or Hellan) Pot is vertical to a depth of 200 feet and is continued by sloping passages and chambers to about 300 feet, at which depth water stops further exploration. The opening is about 100 feet long and 30 feet wide. About halfway down a huge block has jammed in falling, and just above it a stream issues from the wall. The underground course of this stream is a series of narrow rambling passages, known as Long Churn Cave, entrance to which is gained by way of Diccan Pot, 100 yards north-north-west from Allum Pot. Long Churn has been explored for about 750 yards; many of the passages have now been deserted by the water. Stalactites have not been formed in Allum Pot, a fact which leads to the inference that the pot is still undergoing enlargement.

The underground drainage-system connected with Allum Pot is strangely complicated, for the streams cross one another at different levels. The deeper set is that connected with the pot itself; it includes two surface-streams and the water which enters by way of Long Churn. This water, supplemented by some which descends two pots, 1,050 and 1,200 yards respectively north of Allum Pot, issues in time of flood at Footnaw's Hole, more than a mile away. Though Footnaw's Hole lies outside the limits of the model it is worth mentioning that in normal weather the water ceases to issue from it and finds its way by a syphon-like passage under the Ribble to Turn Dub, this most remarkable arrangement being due to the fact that the Ribble flows over, and the Allum Pot water under, an impervious sheet of boulder-clay. The shallower set of the Allum Pot system includes streams which never penetrate far below the surface and which frequently emerge. These are indicated on the model by a dotted line which starts a mile to the south of Allum Pot and crosses the dotted lines leading to Allum Pot.

As regards the northern and north-western flanks of Ingleborough, the underground stream-courses are sufficiently indicated by the

lines upon the model, but the behaviour of the Doe or Dale Beck, which gives its name to Chapel-le-dale, deserves mention. About one-third of a mile within the northern margin of the model the water sinks into crevices, but it reappears in 200 yards from a tunnel known as Gatekirk Cave. After a short course above ground it again vanishes, and some of it, at any rate, does not emerge for upwards of a mile. There are pot-holes at intervals throughout this distance, notably the wide chasm known as Weathercote Cave, out of the side of which the water pours in a cascade 75 feet in height. At the bottom of the chasm the stream runs off to the left in a tunnel-like cave which passes by Jingle Pot and Hurtle Pot.

Jingle Pot is a large chasm, usually shewing a small heap of coarse gravel on its downstream edge. This has been brought from the depths by the uprush of water at the last great flood. The size of the stones and the distance they have been lifted testify to the force of the water.

Hurtle Pot has at its bottom a dark pool of still water, which "hurtles" in the fissures of the limestone, when agitated.

Douk Cave, two-thirds of a mile east of Hurtle Pot, is a good example of the mode of formation of many chasms and ravines in a limestone-country. It has been formed by the collapse of the roof of an underground water-course.

At God's Bridge the Dale Beck finds an underground route in crevices for about 50 yards, but thence downwards remains above ground. Even in the upper part of its course, past the potholes mentioned above, it possesses an open-air channel which is occupied in flood-time.

Yordas Cave is situated in Kingsdale. It expands from a small entrance to a chamber 60 yards long and above 20 yards high, festooned with many stalactites.

River System.

The area illustrated by the model falls within the drainage-system of the Rivers Lune and Ribble, which reach the Irish Sea at Lancaster and Preston respectively. The main water-parting of England which divides these rivers from those which run eastwards to the North Sea, lies four or five miles east of the Ribble head-waters, and ranges from near Settle on the south to the Pennine scarp on the north. Thus the greater part of the Dale District is drained eastwards by rivers which run in the same direction as that in which the strata dip, and which cross an ascending succession of formations. But the western marginal strip of the Dale District, lying between the water-parting and the Craven and Dent Faults, is drained westwards by rivers which at first flow against the dip of the strata, then cross those faults and continue by somewhat tortuous courses to the sea, traversing as they do so a Carboniferous region of complicated geological structures, and paying no regard to anticlines and synclines which come in their way.

Though the water-parting and the great Craven-Dent-Pennine line of disturbance do not coincide, yet they maintain a parallelism which is sufficiently close to suggest a community of origin. For example it is tempting, at first sight, to speculate that one and the same earth-movement caused the faults, gave the strata their

eastward dip and the rivers their eastward courses. The fact that the water-parting now lies a few miles east of the faults would be explained by the head-waters of the westward flowing rivers having cut back rather faster than those on the gentler eastward slopes.

The case, however, is not so simple. We have already noted that the Lune and Ribble pay no regard to the folds in the Carboniferous rocks. The Lune is equally indifferent to the fact that the Dent Fault is a downthrow east ; its tributaries the Dee and Rawthey cross the Dent Fault from the downthrow to the upthrow side, as easily as the Doe and Austwick Beck cross the Craven Fault from the upthrow to the downthrow side. If our hypothesis were good the Dee and Rawthey would start from the westward or uplifted side and flow eastwards, and the water-parting would have been transferred some miles to the west by the cutting-back by head waters. On the contrary the direction of the drainage and the relative position of water-parting and fault are the same in the two cases, regardless of the difference in the throw of the faults.

As a fact it is highly improbable that the Craven-Dent dislocation had any direct share in initiating the river-system. They were produced by earth-movements which are mainly of pre-Triassic age, and the denudation which ensued upon those movements was upon so vast a scale as to modify profoundly any configuration which the land might have acquired as the result of the elevation and depression caused by them.

There are on the contrary reasons for believing that the river-system is of a far more recent creation. The ignoring of geological structures by rivers generally means that the rocks shewing those structures were buried by later undisturbed strata (or as it is called 'blanketed') when the rivers began to flow. The 'blanket' has perished from the region we are discussing, and we can now only guess whether it may have consisted of Jurassic, Cretaceous or Tertiary rocks. But it is to be remembered that in the south of England where the 'blanket' still exists we know that the structures corresponding in age to the Craven Fault were 'blanketed' by Jurassic rocks, that a newer set of structures imposed upon the Jurassic was 'blanketed' by the Upper Cretaceous rocks, and finally that a third set of disturbances which was imposed upon all the strata up to and including Oligocene was the only one which had any direct share in the initiation of the South Country rivers.

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